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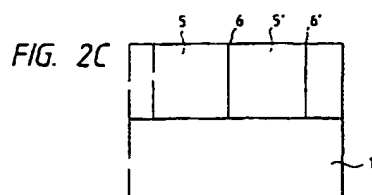
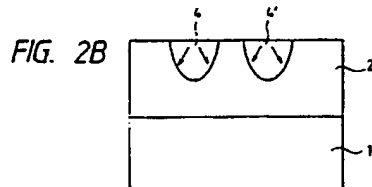
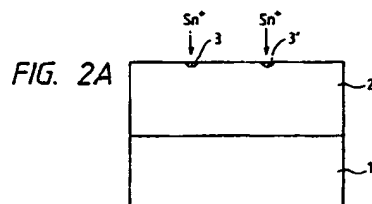
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54 Method for forming semiconductor thin-film and resulting semiconductor thin-film.

57 Polycrystalline silicon thin-films having a large grain size are formed by preparing a substrate of amorphous surface comprising first regions containing tin atoms at a higher content and second regions containing tin atoms at a lower content or not substantially containing them, and then heat-treating the substrate to grow crystal grains from crystal nuclei formed only in the first regions.



## Method for Forming Semiconductor Thin-film and Resulting Semiconductor Thin-film

BACKGROUND OF THE INVENTIONField of the Invention

5 The present invention relates to a method for forming a semiconductor thin-film, and a resulting semiconductor thin-film formed thereby.

More particularly, the present invention relates to a method for forming a semiconductor thin-film of polycrystalline silicon of a large grain size which makes feasible the production of semiconductor devices  
10 such as a thin-film transistor (TFT) and the like having a high performance.

Related Background Art

15 Regarding the technique for forming a polycrystalline silicon semiconductor thin-film of a large grain size, a method was reported in which an amorphous silicon thin-film is allowed to grow in a solid phase to form a polycrystalline silicon thin-film for use for a thin-film transistor [T. Noguchi, T. Ohshima, & T. Hayashi; Polysilicon Films and Interfaces, Boston, 1987, Mater. Res. Soc. Symp. Proc., Vol. 106, p. 293 (Elsevier Science Publishing, New York, 1988)].

20 The detail thereof is described below.

In this method, firstly, an amorphous Si layer is formed on a substrate. The amorphous Si layer may be formed by a known method such as implantation of Si ions into a polycrystalline Si layer for amorphousness, thermal decomposition of  $\text{SiH}_4$  by chemical vapor deposition, and deposition of Si on a substrate kept at room temperature by electron-beam vapor deposition.

25 Subsequently, the amorphous Si layer is heat-treated at  $600^\circ\text{C}$  in nitrogen atmosphere for several to several ten hours. Thereby, crystal nuclei are formed in the amorphous Si layer, and the nuclei grow larger with the lapse of treatment time to result finally in mutual collision of the crystal grains, forming crystal boundaries. For example, an amorphous Si layer of about  $1000\text{ \AA}$  thick formed by Si ion implantation comes to have crystal grains of as large as  $5\text{-}\mu\text{m}$  diameter by thermal treatment at  $600^\circ\text{C}$  for 100 hours. A  
30 thin-film transistor formed on a polycrystalline Si layer having such a large grain diameter is observed to have a carrier mobility of more than  $100\text{ cm}^2/\text{vsec}$ . Accordingly, this treatment is a significantly useful method for grain growth.

However, the inventors of the present invention have found the disadvantages of the above-mentioned prior art as the result of practical experiment and detailed consideration as below.

35 (1) An amorphous silicon layer will not crystallize at a temperature below  $600^\circ\text{C}$ , so that the treating temperature cannot be lowered. For example, no crystal nucleus is formed by a heat treatment at  $550^\circ\text{C}$  for 2000 hours in the silicon layer which is kept amorphous. The temperature  $600^\circ\text{C}$  is generally higher than the heat resistance temperature of glass employed for amorphous Si thin-film transistors. Therefore, heat-resistant expensive quartz glass has to be used as the base material.

40 (2) Generally, crystallization of amorphous thin film by solid-phase crystal growth requires time of as much as several ten hours from the start of heat treatment to achieve complete polycrystalline state independently of temperature. This is because the induction period from the start of the heat treatment to formation of crystal nuclei is as much as several ten hours, and the growth of the crystal nuclei to crystal grain is extremely slow. For example, in amorphous Si formed by  $\text{Si}^+$  ion implantation is observed to exhibit  
45 induction period of about 10 hours at  $600^\circ\text{C}$ , and requires long time of 100 hours from the start of the heat treatment to the completion of crystallization of whole film.

The above two problems is serious in industrial production from the standpoint of production efficiency and production cost, which have to be solved naturally.

50 (3) In addition to the disadvantage (2) above, the nucleus formation in the amorphous Si occurs at random positions, so that the grain boundaries, which are formed by mutual collision of grown crystal grains, formed at random positions, which cannot be controlled. In fact,  $\text{Si}^+$  implantation for amorphousness of the polycrystalline Si layer, and subsequent heat treatment at  $600^\circ\text{C}$  will give a polycrystalline layer having a crystal diameter of  $5\text{ }\mu\text{m}$  at the largest. However, the grain size distributes broadly from  $1\text{ }\mu\text{m}$  to  $5\text{ }\mu\text{m}$ , which gives rise to variation of characteristics of the elements, and may cause a great disadvantage practically.

For example, a field-effect transistor, provided on the above-mentioned polycrystalline Si layer comprising large grains on a 4-inch substrate, exhibits variation of the electron mobility of  $110 \text{ cm}^2/\text{V}\cdot\text{sec}$  relative to  $110 \text{ cm}^2/\text{V}\cdot\text{sec}$  and variation of the threshold value of  $\pm 0.5 \text{ V}$ , which variations are significantly larger than those of the transistor provided on a single crystal Si substrate, giving a large obstruction in constructing an integrated circuit.

(4) Donor-acceptor impurities which modify electrical properties generally such as P, B, As, etc. are known to affect the growth of Si crystal. In particular, P is known to promote abnormal grain growth. (Y. Wada & S. Nishimatsu, J. Electrochem. Soc., Vol. 125, No. 9, p 1499)

The inventors of the present invention, however, after long period of comprehensive study on every kind of impurity, have found that the aforementioned donor-acceptor impurities accelerate crystallization only when the impurity is introduced in a large amount near to the solid-solubility limit, and in that case an n<sup>+</sup> or p<sup>+</sup> layer comes to be formed which is unsuitable for an active semiconductor layer, making difficult the preparation of elements.

15

## SUMMARY OF THE INVENTION

The present invention intends to solve the above-described problems in the prior art.

One object of the present invention is to provide a molded article of a polycrystalline semiconductor thin-film which can be prepared at a low temperature within a short time and having a large size of grain, and a method for preparation thereof.

Another object of the present invention is to provide a method of preparation of a semiconductor film which enables control of the positions of nucleus formation and definition of the position of grain boundary in order to narrow the grain size distribution, and a semiconductor film prepared thereby.

Still another object of the present invention is to provide a crystalline Si semiconductor thin-film which allows the control of the position of nucleus formation in the solid phase, and allows recrystallization at a higher rate at a lower temperature in order to narrow the grain size distribution after the solid phase recrystallization, thus giving a high performance device.

A further object of the present invention is to provide a method for forming a semiconductor thin-film by solid-state growth to give large-grain-size polycrystalline layer in which Sn is added to an amorphous Si layer in order to lower the formation temperature and to shorten the formation time.

A still further object of the present invention is to provide a method for forming a semiconductor thin-film in which the Si layer with Sn contained therein serves normally as an active semiconductor layer owing to a characteristic effect of the neutral impurity without causing problem in preparation of semiconductor-functioning element such as a transistor, and which has improved performance in comparison with those containing no Sn and allows the use of inexpensive glass as a substrate economically because of the low heat-treatment temperature of lower than  $600^\circ \text{C}$  for polycrystalline film formation.

A still further object of the present invention is to provide a method for forming a semiconductor thin-film in which the position of the grain boundaries, which gives obstruction in element preparation, can be controlled by localized addition of Sn to control artificially the nucleation point, and can exclude existence of grain boundaries, which lowers the characteristics of the element, from the functioning region of the element.

A still further object of the present invention is to provide a semiconductor thin-film in which the grain size distribution, which is the main cause of variation of the element in growing the polycrystalline thin-film by conventional solid-phase growth, is narrowed.

A still further object of the present invention is to provide a method for forming a semiconductor thin-film which enables design of nucleation spots artificially at an arbitrary distance, and preparation of large grain of  $10 \mu\text{m}$  or larger in comparison with the maximum grain size of about  $5 \mu\text{m}$  by conventional solid phase growth.

A still further object of the present invention is to provide a method for forming a semiconductor thin-film in which high-Sn-concentration regions are formed locally in Sn-containing amorphous Si to control grain positions in a flat thin film, and crystalline Si thin-film can be formed with narrow grain size distribution at a low temperature with a high productivity.

A still further object of the present invention is to provide a semiconductor thin-film in which devices can be prepared by avoiding grain boundaries because the position of the grain boundary may preliminarily decided so as to avoid grain boundaries which affect adversely the performance of devices in device production, and is capable of giving higher characteristics and narrowing variation of characteristics of elements.

A still further object of the present invention is to provide a method for forming a semiconductor thin-film by which an amorphous layer is preliminarily deposited and the crystal structure only is converted by solid phase growth without causing change of the external shape during the crystal structure conversion, thus crystalline being allowed to grow uniformly in a flat state in an extremely thin layer (for example, not  
 5 more than 1000 Å).

According to one aspect of the present invention, there is provided a method for forming a semiconductor thin-film, comprising heat-treating an amorphous silicon thin-film containing tin (Sn) to cause crystal growth in a solid phase, and a semiconductor thin-film prepared thereby.

According to another aspect of the present invention, there is provided a semiconductor thin-film,  
 10 comprising a substrate, and a polycrystalline Si semiconductor thin-film provided on the substrate and containing Sn in an amount of from  $1 \times 10^{15}$  atom/cm<sup>3</sup> to  $1 \times 10^{22}$  atom/cm<sup>3</sup>.

According to still another aspect of the present invention, there is provided a method for forming a semiconductor thin-film, comprising forming on a substrate an amorphous Si semiconductor thin-film containing added Sn, heat-treating the thin-film at a temperature of not higher than the melting point thereof  
 15 to cause crystallization to form a semiconductor thin-film constituted of polycrystalline Si.

According to further aspect of the present invention, there is provided a method for forming a semiconductor thin-film, comprising providing, in an amorphous silicon thin-film, an Sn-added region to which tin (Sn) is added for forming crystal nuclei on heat-treatment, heat-treating the amorphous silicon thin-film at a temperature below the melting point of the amorphous silicon thin-film, and allowing crystal to  
 20 grow in a solid phase from the crystal nuclei formed in the Sn-added region to form a semiconductor thin-film, and the semiconductor thin-film formed thereby.

According to still further aspect of the present invention, there is provided a method for forming a semiconductor thin-film, comprising providing, at a desired position of amorphous Si film containing tin (Sn), a region having a sufficiently minute area so as to form only one nucleus from which a single crystal is  
 25 grown and having a higher Sn-atom density than other minute region in the amorphous Si film; heat-treating the amorphous Si film at such a temperature that crystal grows from the single nucleus in the minute region and no crystal nucleus is formed in the other region of the amorphous Si film; and allowing crystal to grow in a solid state in the amorphous Si film on the base of the crystal, and a semiconductor thin-film formed thereby.

30

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graph showing the dependency of crystallization-initiating temperature on the implantation  
 35 level of Sn.

Figs. 2A to 2C and Figs. 3A and 3B are schematic explanation of the process of forming the semiconductor thin-film of the present invention.

Fig. 4 and Fig. 5 show effect of Sn addition on the maximum grain size.

Figs. 6A to 6C and Figs. 7a to 7C are schematic explanation of the process of forming the  
 40 semiconductor thin-film of the present invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The inventors of the present invention noticed "a neutral impurity" (Group IV impurity) for solving the  
 45 above-mentioned problems involved in the prior art.

The Group IV impurity which the inventors noticed and which does not impart polarity to a silicon semiconductor when added is required not only to be a neutral impurity but also to have a low melting point and a high solid-solution limit, not to form a dopant level in a band gap of Si, not to form a deep recombination level, and to give a sufficiently long life to carriers.

The inventor of the present invention comprehensively investigated the impurities that satisfy the above requirements, and conducted many experiments repeatedly regarding Sn, consequently having succeeded in lowering the crystallization initiation temperature and in forming polycrystalline film having a large grain size in a short time.

Because of the lowered crystallization initiation temperature in the present invention, the substrate need  
 55 not be highly heat-resistant, so that inexpensive non-single crystal material such as glass may be used as the substrate.

Amorphous Si semiconductor film containing Sn may be formed, for example, by depositing on a substrate a polycrystalline thin film having fine grain size (less than 500 Å) at 600°C by a thermochemical

vapor deposition (CVD) of  $\text{SiH}_4$ , and implanting Sn ions by an ion implantation method, or otherwise electron-beam vapor deposition, glow discharge, sputtering or a like method.

An amorphous silicon thin-film may be formed directly by chemical vapor deposition, and Sn-containing material may be used as a gas component in the chemical vapor deposition.

5 The Sn-containing amorphous Si semiconductor film in the present invention is made polycrystalline by heat treatment. The heat treatment is conducted at a temperature not higher than the melting point of the Sn-containing amorphous Si semiconductor film in a solid state region.

The amount of the addition of Sn is preferably not more than  $1 \times 10^{22}$  atom/cm<sup>3</sup>, since an amount of the addition exceeding  $1 \times 10^{22}$  atom/cm<sup>3</sup> may cause deposition of  $\beta$ -Sn after the heat treatment, which is  
10 unfavorable in forming a semiconductor apparatus. The lower limit of addition of Sn is preferably  $1 \times 10^{15}$  atom/cm<sup>3</sup> since the effect of the present invention can not be achieved generally in a lower amount of addition of Sn.

The thickness of the semiconductor thin-film depends on the device to be formed. For TFT, for example, the thickness is preferably in the range from 500 Å to 2000 Å. Generally the thickness of about  
15 1000 Å is preferable for use as a semiconductor device.

Fig. 1 illustrates the dependency of crystallization temperature (crystallization initiation temperature) on the amount of the implantation in the case where Sn ion is implanted to a polycrystalline Si layer for amorphousness. The Si layer had a thickness of 1,000 Å, and Sn is implanted with implantation energy of 110 keV with the implanting depth reaching approximately middle portion of the Si layer. An increase of the  
20 amount of Sn implantation from  $1 \times 10^{15}$  cm<sup>-2</sup> to  $1 \times 10^{16}$  cm<sup>-2</sup> lowers the temperature of formation of crystal nuclei in the Si layer made amorphous by Sn implantation by 100 °C, namely from 600 °C to 500 °C, which were confirmed by transmission electron microscopy after the heat treatment.

As described above, the inventor of the present invention found the dependency of crystallization initiation temperature on the added amount of Sn, and succeeded to control the nucleation site by changing  
25 locally the Sn concentration in the Si layer by utilizing the above phenomenon. The grain size and the position of the grain boundaries may be controlled by controlling the nucleus forming site.

The invention is described more specifically below.

In order to control the grain size and the grain boundary position of polycrystalline silicon thin-film, the Sn-added region containing locally a high concentration of tin (Sn) should preferably be minute enough for  
30 crystal growth to be caused from a single nucleus. The size of the Sn-added region is preferably not more than 2 μm, still preferably not more than 1 μm, in maximum diameter.

Outside the above-mentioned Sn-added region containing locally a high concentration of tin (Sn), Sn need not be contained, but may be contained in a lower concentration than in the Sn-added region in order to accelerate crystal growth in the solid phase. In the latter case, the concentration of Sn is preferably not  
35 more than  $10^{-2}$  times that in the Sn-added region from the standpoint of positional control of nucleus formation and acceleration of the crystal growth.

The heat treatment is carried out at a temperature below the melting point of the amorphous semiconductor, to cause crystal growth in the solid phase to form a crystalline semiconductor film.

In the heat treatment, the initiation site of the crystal growth in the solid phase is controlled by providing  
40 the Sn-added region containing tin (Sn) locally in a high concentration in the amorphous silicon thin-film.

This positional control of nucleus formation in the solid phase is conducted on the basis of the finding that the crystallization initiates at a lower temperature in the Sn-added region than in a Sn-non-added region. In order to control the position of the grain boundary, the heating temperature is preferably such that the crystal grows from the nucleus formed in the Sn-added region but a nucleus cannot be formed in an  
45 Sn-non-added region. The semiconductor thin-film can be formed at a relatively low temperature of from 500 °C to 650 °C. If glass is used as the substrate material, the maximum temperature of the heat treatment is preferably below 600 °C to prevent deformation of the substrate material.

In the case of amorphous Si and Sn employed, as shown in Fig. 2, Sn is added locally to the predetermined sites inside the amorphous Si 2 formed on a  $\text{SiO}_2$  substrate 1 (Fig. 2A), and subsequently  
50 heat treatment is conducted at such a temperature that Sn-containing amorphous Si (Sn-added region) 3 only will crystallize to form nuclei. In the other amorphous Si region (Sn-non-added region), no nucleus is formed because the crystallization temperature thereof is sufficiently higher than that of the impurity-added region. Continuation of the heat treatment causes the growth of the positionally controlled nuclei into amorphous Si region (Fig. 2B). This is because the phase transition of amorphous Si phase to a crystalline  
55 phase having a nucleus formed will occur with lower energy than the activation energy required for nucleus formation in an amorphous phase. Further continuation of the heat treatment gives rise to collision of the positionally controlled crystal grains 4 and 4', forming a grain boundary 6 between the nucleus-forming positions (Fig. 2C).

Fig. 3 shows control of the position of the nucleus formation by forming the regions locally containing a higher concentration of Sn.

An amorphous Si layer with Sn added is formed on a substrate material. In the layer, regions having locally a higher concentration of Sn are formed at a predetermined spacing (Fig. 3A). The substrate is treated thermally to cause solid phase recrystallization at a temperature such that only the regions of a higher Sn concentration crystallize, i.e. lower than the temperature of crystallization of the regions of a lower Sn concentration, thus forming Si nuclei only in the region of a higher Sn concentration. Further continuation of the heat treatment leads to growth of the crystal in the solid phase into the region of a lower Sn concentration forming no nucleus, causing collision with the grain generated at the adjacent region of higher Sn concentration around the midpoint, thereby the amorphous Si region disappearing and a positionally controlled grain boundary being formed at the position of the collision (Fig. 2B).

The Si nucleus is formed at a portion of a high Sn density, the crystal growing in solid phase keeping a single domain to a low density portion, since the activation energy for growth of crystal from a nucleus having once formed is lower than the activation energy for nucleus formation to surmount the barrier of the surface energy.

The Examples of the present invention are described below.

#### Example 1

On a glass plate as a substrate, a polycrystal layer constituted of fine grains (less than 500 Å in diameter) was deposited by thermochemical vapor deposition of  $\text{SiH}_4$  at 600 °C to a thickness of 1,000 Å.

The ion implantation was conducted into the polycrystal layer under the conditions shown in Table 1.

Sample No.	Implanted ion	Accelerating voltage (kV)	Dose ( $\text{cm}^{-2}$ )
0	Si	70	$5 \times 10^{15}$
1	Sn	110	$1 \times 10^{15}$
2	Sn	110	$1 \times 10^{16}$
3	Sn	110	$1 \times 10^{17}$

The accelerating voltage of 110 kV was selected so that the projection range (implantation depth) reaches the middle of the Si layer, resulting in the range of 498 Å from the surface.

As shown in Table 1, into Sample of No. 0, Si ion was implanted with a dose of  $5 \times 10^{15}$  ion/ $\text{cm}^2$  at 70 kV, and into Samples of No. 1 to 3, Sn ion was implanted at 70 kV with doses of  $1 \times 10^{15}$ ,  $1 \times 10^{16}$ , and  $1 \times 10^{17}$  ion/ $\text{cm}^2$ , respectively.

Samples of No. 0, No. 1, and No. 2 as implanted, or before the heat treatment had an structure of amorphous Si according to the observation by transmission electron microscopy, and exhibited in electron beam diffraction a halo pattern which is characteristic to amorphous Si. On the other hand, Sample of No. 3 into which Sn was implanted at a higher concentration of  $1 \times 10^{17}$  ion/ $\text{cm}^2$  (corresponding to Sn concentration of  $1 \times 10^{22}$  ion/ $\text{cm}^3$  in the 1,000Å-thick Si layer) crystallized already at the time of implantation, and was found to have  $\beta$ -Sn deposited after heat treatment at about 500 °C by scanning type transmission electron microscopy. Accordingly the tests below were omitted as to this sample.

Samples of No. 0, No. 1, and No. 2 were subjected to constant-temperature heat treatment at the temperature of 600 °C in a nitrogen atmosphere as shown in Fig. 4. Consequently, in the Si layer made amorphous by implantation of Si ion without Sn addition, nuclei were formed in the amorphous Si only after 10 or more hours of induction period, and thereafter the crystal extended in a dendrite form to cause collision with the adjacent crystal grain, resulting in disappearance of amorphous region and crystallization of the whole layer, thus giving a thin-film polycrystal. In approximately 100 hours, the maximum grain size became saturated with the grain size exceeding 5  $\mu\text{m}$ .

In Sample of No. 1, into which Sn was implanted with a dose of  $1 \times 10^{15}$  ion/ $\text{cm}^2$ , the induction period was approximately 6 hours, and the formed crystal became saturated in 20 hours with the maximum grain size of about 4.8  $\mu\text{m}$ .

In Sample of No. 2, into which Sn was implanted at a higher concentration with a dose of  $1 \times 10^{16}$

ion/cm<sup>2</sup>, the induction period was 3 hours or less, and the maximum grain size became saturated at about 4.5  $\mu$ m in 6 hours.

The maximum saturated grain size decreased with the increase of the Sn dose. This is considered to be due to the increase of nucleus forming rate with the increase of the amount of Sn added. The increase of the Sn addition is considered to give rise to an increase of the nucleation density at the time of grain collision in the amorphous Si, resulting in some decrease of the grain size.

Fig. 5 illustrates the dependency of the grain size on heat-treatment temperature at the treatment for 100 hours constantly under a nitrogen atmosphere. In Sample of No. 0 not containing Sn, no crystallization occurred below 600 °C even with 100 hours or more of heat treatment, while at 600 °C or a higher temperature the nucleation density increased, with tendency of a smaller grain size at a higher heat-treatment temperature because of the higher nucleation density at a higher temperature. In Sample No. 1, into which Sn was implanted with a dose of  $1 \times 10^{15}$  ion/cm<sup>2</sup>, the crystallization initiated at 500 °C that is lower by 100 °C than the samples without addition, and the nucleation density could be kept lower than that at 600 °C, so that the maximum grain size approached to approximately 10  $\mu$ m by heat treatment for 100 hours.

In Sample of No. 2, into which Sn is added with a dose of  $1 \times 10^{16}$  ion/cm<sup>2</sup>, the crystallization initiated at a temperature as low as 450 °C, giving the maximum grain size exceeding 10  $\mu$ m.

As described above, the induction period could be shortened and the crystallization temperature could be lowered by addition of Sn, and the crystal grain was made possible to grow to a larger size.

An FET (Field-effect transistor) was prepared by use of the Sn-doped polycrystal thin-film of a large grain size obtained by the present invention according to a usual IC process. The FET exhibited normal static characteristics of a transistor as one formed on a film containing no Sn, with the carrier mobility increasing with increase of the grain size, resulting in improvement by 20 to 40 % (120 to 140 cm<sup>2</sup>/vsec in electron mobility). Additionally, crystallization occurred at 500 °C or lower, which permits the use of inexpensive glass, giving economical effects.

#### Example 2

The method of addition of Sn into an Sn thin-film is not limited to ion implantation. Other method is described below.

An amorphous Si thin-film was formed on a glass substrate by vacuum chemical vapor deposition at a treatment temperature of 550 °C to give a thickness of 1,000 Å.

Subsequently Sn layer was deposited on the surface of the amorphous Si to a thickness of 50 Å by vacuum vapor deposition, which was heat-treated at temperatures of from 400 °C to 600 °C. In the heat treatment, the crystallization initiated at 450 °C similarly to the preceeding Example, giving a similar grain size thereto (approximately 10  $\mu$ m).

The surface layer was treated with a mixture of hydrofluoric acid and nitric acid to remove the remaining Sn, thus providing a transistor which has satisfactory characteristics similar to those in the preceeding Example.

#### Example 3

On an amorphous SiO<sub>2</sub> substrate 1 (thermally oxidized Si or glass), polycrystalline Si was deposited at 620 °C to a thickness of 1,000 Å by vacuum chemical vapor deposition. Further, Si ion was implanted over the entire surface thereof with an accelerating energy of 70 keV with a dose of  $5 \times 10^{15}$  ion/cm<sup>2</sup>, to change the polycrystalline Si into an amorphous Si 2.

Sn impurity was locally added by focusing ion beam implantation in a maskless process under the conditions of an Sn<sup>++</sup> beam diameter of 0.1  $\mu$ m, a dose of  $1 \times 10^{15}$  ion/cm<sup>2</sup>, an accelerating energy of 50 keV, spacings of 10  $\mu$ m, 20  $\mu$ m, and 30  $\mu$ m in a lattice arrangement, in a size of 2  $\mu$ m square, to form implanted portions (Sn-added region) 3 (Fig. 2A).

Subsequently, heat treatment was conducted therewith at 550 °C for 100 hours in an nitrogen atmosphere to grow Si crystal 4. Since no nucleus was formed in Sn-non-added amorphous Si during the heat treatment, so that crystal regions 5 extend from the Sn-implanted region in a dimension of approximately 10  $\mu$ m, and the grain boundaries 6 were formed at the midpoints between the implanted sites (Fig. 2B and Fig.2C). The grain sizes were confirmed to distribute respectively in the range of  $10 \mu\text{m} \pm 1 \mu\text{m}$ ,  $20 \mu\text{m} \pm 2 \mu\text{m}$ , and  $30 \mu\text{m} \pm 3 \mu\text{m}$  by transmission electron microscopy.



Example 4

On an  $\text{SiO}_2$  substrate, amorphous Si was deposited to a thickness of 1,000 Å at 550 °C by vacuum chemical vapor deposition. Thereafter, Sn-added regions of 1 μm square were formed in the amorphous Si in lattice arrangement by implanting Sn at a dose of  $1 \times 10^{15}$  ion/cm<sup>2</sup> by employing a resist as a mask having apertures of 1 μm square at a spacing of 10 μm, 20 μm, or 30 μm with an accelerating energy of 50 keV. After removal of the resist, the amorphous Si was heat-treated at 550 °C for 100 hours in a nitrogen atmosphere. The observation of crystal structure by transmission electron microscopy showed that the grain boundaries were formed in lattice arrangement between the Sn-implanted regions with grain sizes respectively of 10 μm ± 1 μm, 20 μm ± 2 μm, and 30 μm ± 3 μm.

Example 5

As shown in Fig. 6, Sn was deposited by vacuum vapor deposition in a thickness of 100 Å on an amorphous  $\text{SiO}_2$  substrate 1, and then the Sn thin-films 7 were formed in 1 μm square at a spacing of 10 μm, 20 μm, or 30 μm according to photolithography (Fig. 6A).

Further thereon, an amorphous Si layer 2 was deposited at 100 °C to a thickness of 1,000 Å by plasma chemical vapor deposition. Then the Si crystals 4 were allowed to grow by heat treatment at 550 °C for 100 hours (Fig. 6B and Fig. 6C). The observation of crystal structure by transmission electron microscopy shows that the grain boundaries 6 of the Si crystals 5 were formed between the Sn regions with the grain sizes respectively of 10 μm ± 1 μm, 20 μm ± 2 μm, and 30 μm ± 3 μm. The Sn melted during the heat treatment (550 °C) and diffused into Si since the Sn layer has a melting point of 232 °C.

Example 6

As illustrated in Fig. 7, polycrystalline Si was deposited at 620 °C to a thickness of 1,000 Å on an  $\text{SiO}_2$  substrate 1 by vacuum chemical vapor deposition. Subsequently Si ions were implanted over the entire surface thereof with a dose of  $5 \times 10^{15}$  ion/cm<sup>2</sup> with an accelerating energy of 70 keV to change the polycrystalline Si layer into an amorphous Si layer 2. Further thereon, an Sn layer was formed to a thickness of 100 Å by vacuum vapor deposition (at room temperature). The Sn regions 7 of 1 μm square were formed at a spacing of 10 μm, 20 μm, or 30 μm by photolithography. Then the Si crystals 4 were allowed to grow by heat treatment at 550 °C for 100 hours in a nitrogen atmosphere. After etching for development of latent defects, observation of crystal structure by scanning electron microscopy showed that the grain boundaries of the resulting Si crystals 5 were located at the mid points between the Sn region in lattice arrangement, and the grain sizes were 10 μm ± 1 μm, 20 μm ± 2 μm, and 30 μm ± 3 μm respectively corresponding to the spacings of the Sn region.

Example 7

A polycrystalline Si thin-film was deposited to a thickness of 1,000 Å on a glass substrate by thermal decomposition of  $\text{SiH}_4$  according to vacuum chemical vapor deposition at 620 °C. The grain size of the formed polycrystalline Si thin-film was not more than 500 Å.

Thereafter Sn ion implantation was conducted twice. Firstly Sn<sup>+</sup> was implanted over the entire surface with an implantation dose of  $1 \times 10^{15}$  ion/cm<sup>2</sup> with an implantation energy of 110 keV to make amorphous the entire body of the polycrystalline Si thin-film. Then a resist was applied and holes of 1 μm diameter were provided therein by usual lithography with a spacing of 5 μm or 10 μm in lattice arrangement. The second Sn ion implantation was conducted by employing the patterned resist as the mask with an implantation dose of  $1 \times 10^{15}$  ion/cm<sup>2</sup> and implantation energy of 50 keV. After peeling-off of the resist mask, heat treatment was conducted at 500 °C for 50 hours in a nitrogen atmosphere. Observation by transmission electron microscopy showed that the grain boundaries were arranged in an unchanged flat film of 1,000 Å at spacing of 5 μm, or 10 μm in lattice arrangement, and the distribution of the grain size were 11 μm for the averages of 5 μm, and 10 μm. In the amorphous Si layer which had not been subjected to the second Sn addition treatment, no crystal nucleus was formed by the heat treatment at 500 °C for 50 hours, which shows that the Sn addition in this Example achieved the shortening of the latent period of nucleus formation and increase of growth rate.

The Si layer of the starting material may, of course, be amorphous as deposited. Amorphous Si provided by vacuum chemical vapor deposition at 550 °C or amorphous Si containing hydrogen provided by glow discharge may also be employed as the starting material, giving the similar effect. The ion implantation may be conducted by a maskless process by employing a focused ion implantation method.

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#### Example 8

On a 4-inch glass substrate, an Sn-added Si thin film was formed which has grain size distribution of 5  $\mu\text{m}$  to 1  $\mu\text{m}$  according to the present invention, from which 100 field-effect transistors with a channel length of 3  $\mu\text{m}$  were prepared according to the usual IC process. The electron mobility thereof was  $200 \pm 10 \text{ cm}^2/\text{vsec}$ , and the threshold value was  $1.5 \pm 0.2 \text{ V}$ . The channel portion of the transistor could be arranged so as not to include any grain boundary since the location of the grain boundaries are preliminarily known, whereby the characteristics of the elements are improved and distributed within a narrow range.

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#### Claims

1. A method for forming a semiconductor thin-film, comprising heat-treating an amorphous silicon thin-film containing tin (Sn) to cause crystal growth in a solid phase.
2. The method of Claim 1, wherein the amorphous silicon thin-film contains tin in an amount of from  $1 \times 10^{15} \text{ atom/cm}^3$  to  $1 \times 10^{22} \text{ atom/cm}^3$ .
3. The method of Claim 1 wherein the amorphous silicon thin-film is heat-treated at a temperature of not higher than 650 °C.
4. A semiconductor thin-film, prepared by the method of Claim 1.
5. The method of Claim 1, wherein the amorphous silicon thin-film comprises a first region containing tin and a second region not containing tin.
6. The method of Claim 5, wherein the first region contains tin in an amount of from  $1 \times 10^{15} \text{ atom/cm}^3$  to  $1 \times 10^{22} \text{ atom/cm}^3$ .
7. The method of Claim 5, wherein the second region contains tin in an amount of less than  $10^{-2}$  times the content in the first region.
8. A semiconductor thin-film, comprising a substrate, and a polycrystalline Si semiconductor thin-film provided on the substrate and containing Sn in an amount of from  $1 \times 10^{15} \text{ atom/cm}^3$  to  $1 \times 10^{22} \text{ atom/cm}^3$ .
9. The semiconductor thin-film of Claim 8, wherein the substrate comprises a non-single-crystalline material.
10. A method for forming a semiconductor thin-film, comprising forming on a substrate an amorphous Si semiconductor thin-film containing added Sn, heat-treating the thin-film at a temperature of not higher than the melting point thereof to cause crystallization to form a semiconductor thin-film constituted of polycrystalline Si.
11. The method of Claim 10, wherein the amorphous Si semiconductor thin-film contains tin in an amount of from  $1 \times 10^{15} \text{ atom/cm}^3$  to  $1 \times 10^{22} \text{ atom/cm}^3$ .
12. A method for forming a semiconductor thin-film, comprising providing, in an amorphous silicon thin-film, an Sn-added region to which tin (Sn) is added for forming crystal nuclei on heat-treatment, heat-treating the amorphous silicon thin-film at a temperature below the melting point of the amorphous silicon thin-film, and allowing crystal to grow in a solid phase from the crystal nuclei formed in the Sn-added region to form a semiconductor thin-film.
13. The method of Claim 12, wherein the Sn-added region is sufficiently minute for crystal so as to form only a nucleus from which a single crystal is grown.
14. The method of Claim 12, wherein the heat treatment is conducted at a temperature which allows crystal growth from the nucleus formed in the Sn-added region in the solid phase but does not allow formation of a nucleus outside the Sn-added region.
15. The method of Claim 12, wherein the amorphous silicon thin-film contains tin (Sn) outside the Sn-added region in a concentration lower than the tin content of the Sn-added region.
16. A semiconductor thin-film formed by the method of Claim 12.
17. A method for forming a semiconductor thin-film, comprising providing, at a desired position of amorphous Si film containing tin (Sn), a region having a sufficiently minute area so as to form only one nucleus from which a single crystal is grown and having a higher Sn-atom density than other region in the amorphous Si film; heat-treating the amorphous Si film at such a temperature that crystal grows from the

single nucleus in the minute region and no crystal nucleus is formed in the other region of the amorphous Si film; and allowing crystal to grow in a solid state in the amorphous Si film on the base of the crystal.

18. The method of Claim 17, wherein the amorphous Si film comprising a region having a higher Sn-atom density is formed by first ion implantation over the entire surface of a polycrystalline Si film to make  
5 the polycrystalline Si film amorphous, and by subsequent second ion implantation only to the minute region.

19. The method of Claim 18, wherein the amorphous Si film is formed on a substrate material; the first ion implantation is conducted with a higher energy so that the projection range having the maximum concentration of implanted ion comes to the interface between the substrate material and the amorphous Si film; and the second ion implantation is conducted with a lower energy so that the projection range reaches  
10 the middle of the thickness of the amorphous Si film.

20. The method of any one of Claims 17 to 19, wherein the region having the higher Sn-atom density is provided in a single number.

21. The method of any one of Claims 17 to 19, wherein the region having the higher Sn-atom density is provided in plurality.

15 22. A semiconductor thin-film formed by the method of Claim 17.

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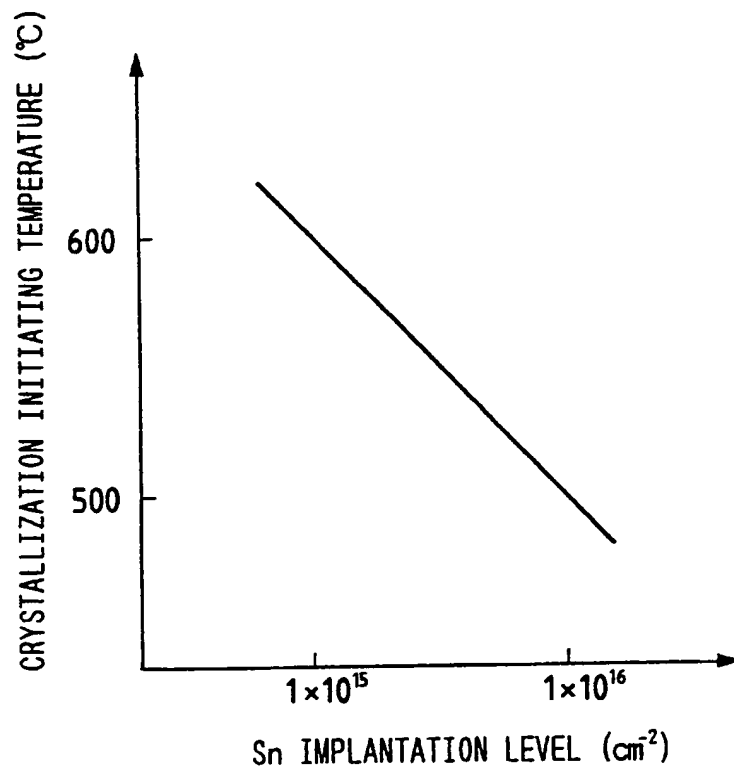
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FIG. 1



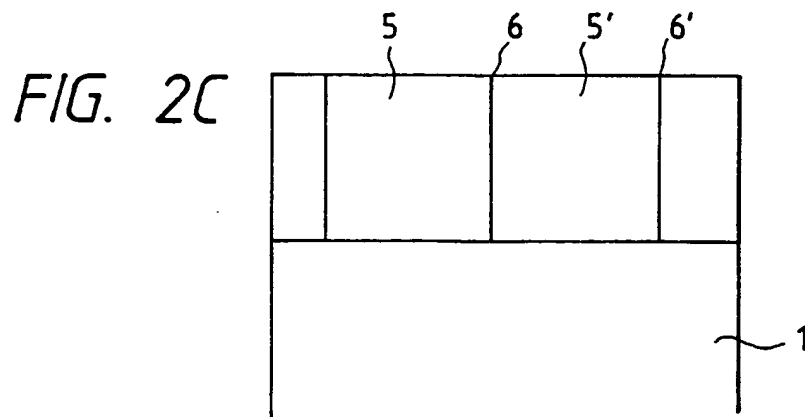
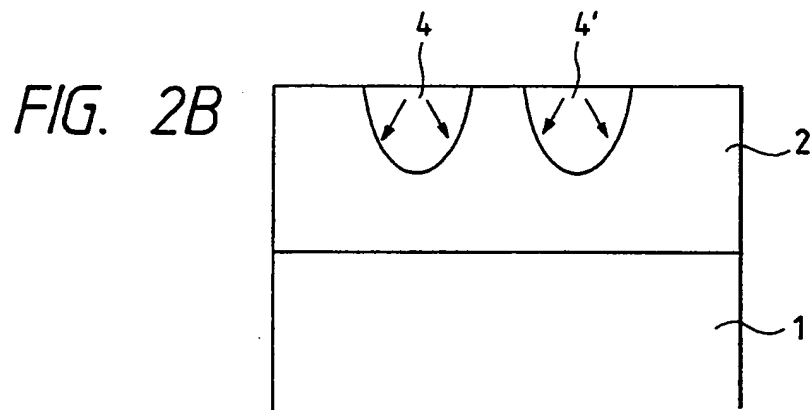
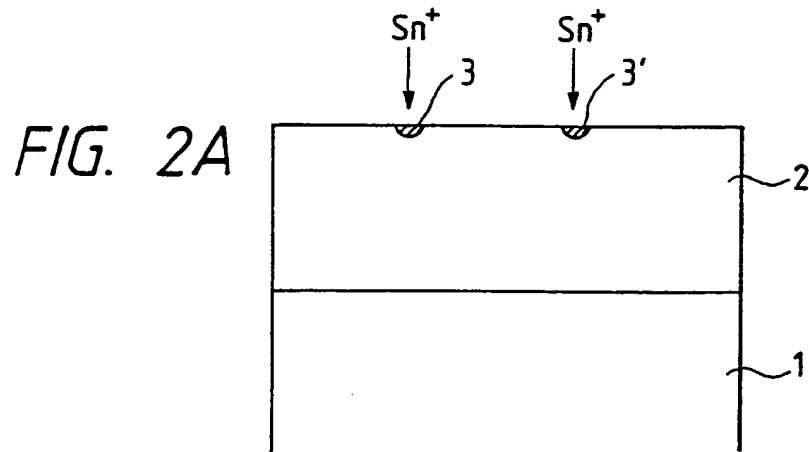


FIG. 3A

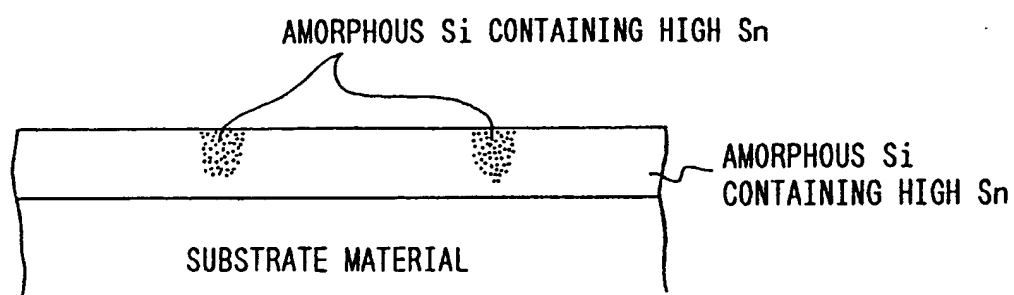


FIG. 3B

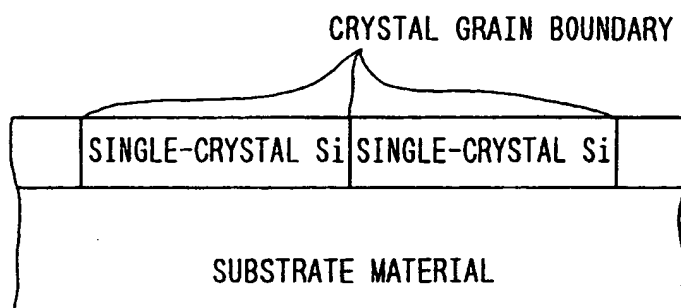
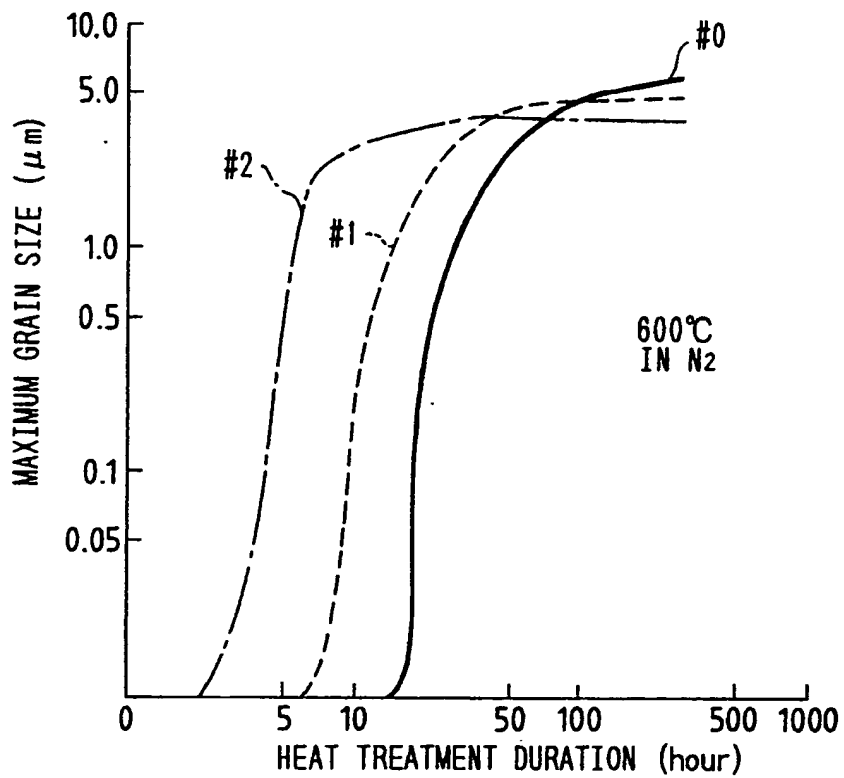


FIG. 4



#0: Sn NO ADDITION ( $\text{Si}^+$  70kV  $5 \times 10^{15} \text{ IONS/cm}^2$ )  
 #1: Sn 110kV  $1 \times 10^{15} \text{ IONS/cm}^2$  IMPLANTATION  
 #2: Sn 110kV  $1 \times 10^{16} \text{ IONS/cm}^2$  IMPLANTATION

FIG. 5

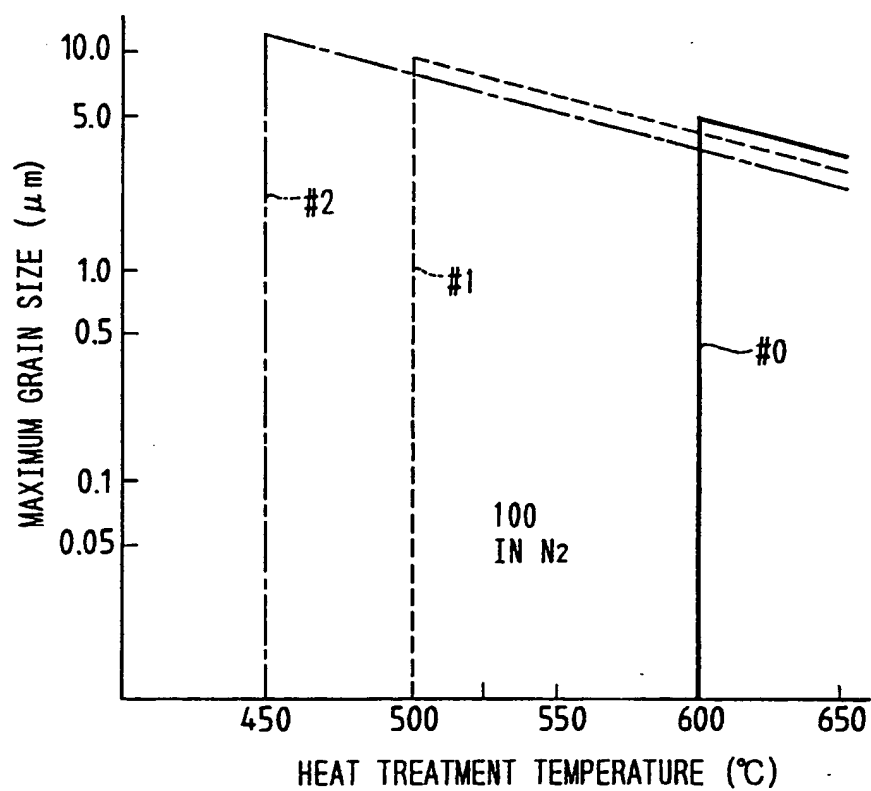




FIG. 6A

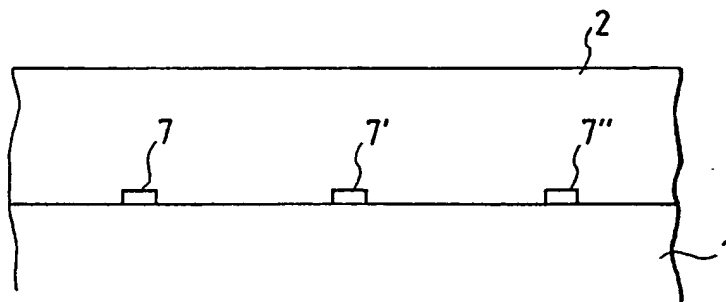


FIG. 6B

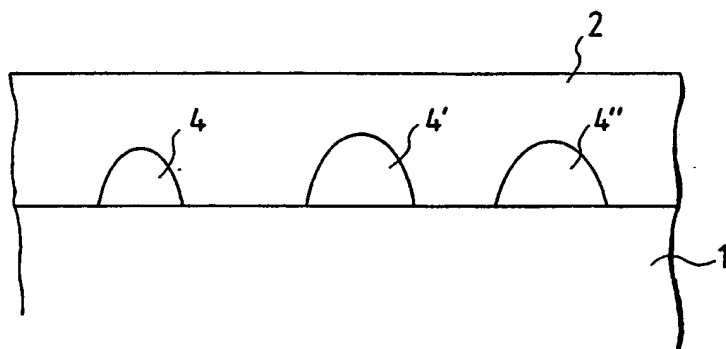


FIG. 6C

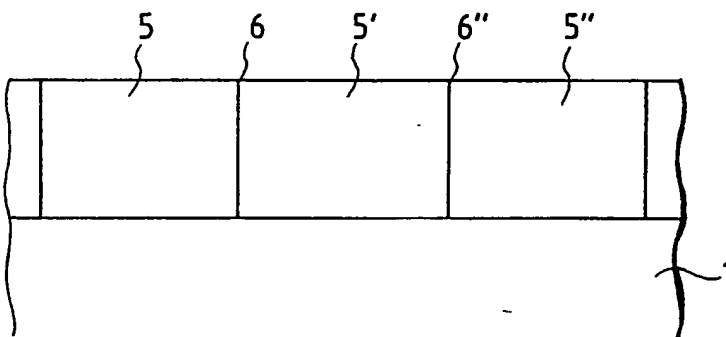


FIG. 7A

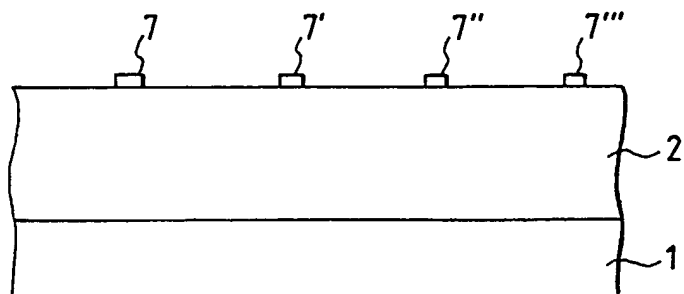


FIG. 7B

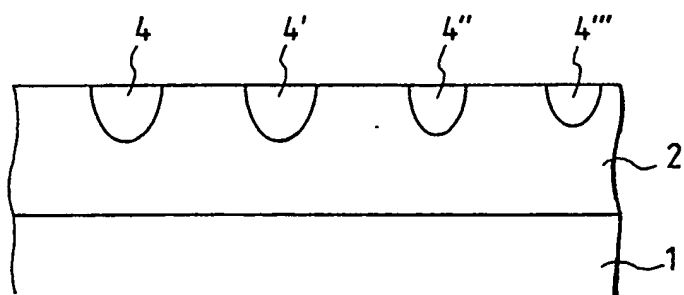


FIG. 7C

